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RESEARCH PAPER

Effects of surfactants and simulated rainfall on the efficacy of the Engame formulation of glyphosate in johnsongrass, prickly sida and yellow nutsedge

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The effects of surfactants and simulated rain were investigated on the efficacy of Engame and Roundup Ultramax formulations of glyphosate on johnsongrass (*Sorghum halepense* L.), prickly sida (*Sida spinosa* L.) and yellow nutsedge (*Cyperus esculentus* L.). Flame surfactant provided the greatest enhancement of Engame efficacy and the effect was species-dependent. Flame enhanced the activity of Engame on johnsongrass and yellow nutsedge but not on prickly sida. Engame and Engame plus Flame were more active than Roundup Ultramax on a glyphosate acid-equivalent basis on johnsongrass without rain, and on yellow nutsedge with or without rain. The Engame and Roundup Ultramax activities on johnsongrass were similar with rain, and rain occurring between five and 30 min after treatment diminished their activities to <38% of the control. With the addition of Flame surfactant, Engame activity on johnsongrass increased, such that 50% and 80% of the control were realized, even with rain occurring between five and 15 min after treatment, respectively. Engame and Roundup Ultramax provided better control of prickly sida than of johnsongrass following a rain event. The addition of Flame surfactant to Engame did not enhance the activity on prickly sida. Yellow nutsedge control with Engame and Engame plus Flame was greater than with Roundup Ultramax and rain had little effect on control regardless of the length of the rain-free period. These results demonstrated that the activities of Engame, Engame plus Flame and Roundup Ultramax were species-dependent and surfactant-dependent.

Keywords: AMADS, Engame, glyphosate, rainfastness, surfactant.

INTRODUCTION

Engame is a new formulation of glyphosate that contains glyphosate acid and a proprietary blend of urea and sulfuric acid called AMADS (1-aminomethanamide dihydrogen tetraoxosulfate), which has synergistic properties with glyphosate (Platte Chemical Company 2001). The Engame formulation has increased efficacy over formulations consisting of glyphosate salt and surfactants (Molin 2000; Parrish 2002; Westra *et al.* 2002; Molin *et al.* 2003; Westra *et al.* 2003; Molin & Hirase 2004). Engame should be applied with a surfactant, such as LI-700, Activator 90 or Flame (Platte Chemical Company 2001). However, surfactant efficacies and rates have not been described. In addition, because the pH of the prepared Engame solution for application is <2, it is not known how low pH would affect surfactant efficacy.

The addition of surfactants to glyphosate formulations has been shown to improve glyphosate activity under certain conditions. Surfactant efficacy in increasing weed control with glyphosate or other herbicides has varied with the type of surfactant used (Roggenbuck *et al.* 1990; Boydston & Al-Khatib 1994; Miller *et al.* 1998) and with the type of herbicide (Boydston & Al-Khatib 1994; Roggenbuck *et al.* 1990). In addition, the species

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and growth stage under evaluation (Roggenbuck *et al.* 1990; Reddy & Singh 1992) and the type of formulation (Feng *et al.* 2000) also were factors affecting surfactant efficacy in improving control with glyphosate. Surfactant efficacy in increasing weed control with glyphosate was also dependent on the duration of the rain-free period (Bryson 1987; Bovey *et al.* 1990; Reddy & Singh 1992; Bariuan *et al.* 1999). Adjuvant effectiveness might also vary with pH.

Rainfastness has been defined as the time required after a pesticide application for enough absorption to occur for activity not to be diminished by subsequent rainfall (Fagerness & Penner 1998). The time interval to achieve rainfast treatments is critical to postemergence herbicides, especially in cases where uptake is slow or where the herbicide can be readily washed from the leaf surface. For example, glyphosate activity was reduced by ≈80% when rainfall occurred within 4 h of treatment (Bryson 1987; Bovey *et al.* 1990). Similarly, glyphosate efficacy was reduced by one half and one third when simulated rainfall occurred at 1 h and 24 h, respectively, after glyphosate application compared with no rain (Bariuan *et al.* 1999). The loss of glyphosate activity due to rainfall was prevented when the rain-free period was extended to 72 h. Feng *et al.* (2000) found that the efficient uptake of Roundup was correlated with rainfastness. They showed that glyphosate uptake and translocation were nearly twofold with the Roundup Ultra formulation compared to the Roundup Original and Sulfosate 5 formulations. In addition, growth inhibition of velvetleaf by the Roundup Ultra formulation following rainfall was nearly twice that of the other formulations. Thus, the greater efficacy of Engame compared to other glyphosate products would result in faster uptake and translocation, which would translate into its greater rainfastness.

The objectives of this study were to compare the efficacy of Engame, Engame with surfactant and Roundup Ultramax for the control of prickly sida, johnsongrass and yellow nutsedge, and to determine the effect of simulated rainfall on the efficacies of these formulations.

MATERIALS AND METHODS

Prickly sida and johnsongrass were established from seeds and yellow nutsedge from tubers. Seeds or tubers were placed in 10 cm diameter pots containing a 4:1 (w/w) mixture of soil (Dundee silty clay loam, fine-silty, mixed thermic Aeric Ochraqualf) and Jiffy Mix (Jiffy Products of America, Batavia, IL, USA). The pots were placed in a greenhouse at 30 ± 2°C and underwent a 14 h photoperiod. The pots were subirrigated as needed and fertilized biweekly with 50 mL of 1% (w/v) general-purpose, water-soluble fertilizer (Scotts-Sierra Horticultural Products, Marysville, OH, USA). Herbicides were applied when plants reached the four-leaf stage of growth.

The herbicides were applied with a pneumatic track sprayer (Allen Machine Works, Midland, MI, USA) with flat fan nozzle tips (Teejet 8002; Spraying Systems, Wheaton, IL, USA) delivering 187 L ha^{-1} water at 179 kPa. In the surfactant study, Engame was applied alone or with surfactant at concentrations specified in Table 1. The surfactants consisted of Phase, a blend of methylated esters of fatty acids and organosilicone fluid (Loveland Industries, Greeley, CO, USA); Flame, a blend of polyoxyethylene amine surfactant, alkyl polyoxyethylene ethers and ethoxylated derivatives (Loveland Industries, Greeley, CO, USA); LI700, a blend of phosphatidylcholine, methylacetic acid and alkyl polyoxyethylene ether (Loveland Industries, Greeley, CO, USA); Induce, a blend of alkylaryl polyoxyalkene ether and free fatty acids (Helena Chemical Company, Collierville, TN, USA); and Breakthru, a polyether-polymethylsiloxane-copolymer (Goldschmidt Chemical Corporation, VA, USA). These surfactants are wetting and spreading agents used to improve coverage and penetration.

In studies on the effects of precipitation on the efficacy of Engame, Engame plus Flame and Roundup Ultramax, spray solutions were applied at a rate of 890 g of glyphosate acid-equivalents ha^{-1} to prickly sida and yellow nutsedge, and at a rate of 560 g glyphosate acid-equivalents ha^{-1} to johnsongrass. Rainfall was applied with a pressure-regulated simulator (Meyer & Harmon 1979), which produced drop sizes and fall velocities characteristic of natural rain. At a predetermined time after herbicide application, plants received simulated rainfall at a constant rate of 6 cm h^{-1} for 10 min. The duration between herbicide application and rainfall initiation was five, 10, 15 and 30 min for johnsongrass and 15, 30, 60, 90 and 120 min for prickly sida. After receiving the precipitation, plants were allowed to dry and then returned to the greenhouse. Test plants were evaluated qualitatively for visible injury, expressed as growth reduction relative to untreated plants (control) at two weeks after treatment. Data were recorded as percentage injury, where 0% was no injury and 100% was complete kill.

A randomized, complete-block design with three replications was used in the surfactant experiment and the

Table 1. The effects of adjuvants on Engame activity in johnsongrass, prickly sida and yellow nutsedge at two weeks after treatments

Surfactant	Concentration (%)	Johnsongrass (% control)					Prickly sida (% control)					Yellow nutsedge (% control)				
		Engame (kg ha^{-1})														
		0.07	0.14	0.28	0.56	1.12	0.07	0.14	0.28	0.56	1.12	0.07	0.14	0.28	0.56	1.12
Breakthru	0.10	30	67	99	99	99	13	35	70	87	93	0	5	28	52	62
LI700	0.25	57	99	99	99	99	3	28	65	87	98	0	8	35	62	75
Induce	0.25	38	92	99	99	99	8	30	63	88	90	0	5	27	57	68
Phase	0.50	27	88	99	99	99	8	63	83	90	90	0	13	22	55	73
Flame	0.25	99	99	99	99	99	33	63	87	93	98	2	25	45	72	87
Flame	0.50	99	99	99	99	99	23	70	87	95	97	5	25	63	87	82
Flame	1.00	99	99	99	99	99	13	48	75	93	98	15	17	63	72	87
None	–	3	33	93	99	99	2	42	95	95	98	0	5	28	45	60
LSD (0.05)	–	20	12	3	2	2	11	14	11	6	4	5	10	16	19	20

LSD, least significant difference.

experiment was repeated. A randomized, complete-block design with four replications was used in the simulated rainfall experiments and the experiment was repeated. Data were not significantly different between repeats and the pooled data are presented.

RESULTS AND DISCUSSION

Engame activity on johnsongrass and yellow nutsedge was enhanced by the inclusion of surfactants in the spray solution (Table 1). However, Engame activity on prickly sida was greater without surfactant than with surfactant at rates >0.14 kg ha^{-1} (Table 1). These results indicate that there is a difference among species in their sensitivity to Engame, which was also shown for other glyphosate formulations (Molin & Hirase 2004).

Flame surfactant provided the greatest enhancement of Engame activity among the surfactants tested (Table 1), at low to moderate Engame rates. At 0.07 kg ha^{-1} of Engame, the relative activity of the surfactants for enhancing Engame control of johnsongrass was: Flame > LI 700 > Induce = Breakthru = Phase. However, at 0.14 k ha^{-1} of Engame, the relative activity of the surfactants for enhancing Engame control of johnsongrass was: Flame = LI 700 = Induce = Phase > Breakthru. At rates >0.14 kg ha^{-1}, differences among the surfactants in enhancing Engame efficacy could no longer be distinguished because Engame by itself completely controlled johnsongrass. A similar pattern of surfactant enhancement of Engame activity was observed on yellow nutsedge (Table 1), although the level of control of yellow nutsedge was less than johnsongrass at equivalent rates of Engame.

The efficacy of glyphosate formulations consisting of Engame, Engame plus Flame and Roundup Ultramax following rainfall events are presented in Table 2. Johnsongrass control was >90% for Engame and Engame plus Flame compared to 65% with Roundup Ultramax in plants without rainfall (Table 2). A precipitation delay of 30 min following glyphosate application reduced the control of johnsongrass from 93–38% with Engame and from 66–22% for Roundup Ultramax. However, when Flame was added to Engame, johnsongrass control only decreased from 98 to 82% and 54% of the control was observed even when the rain delay was only 5 min. These results indicate that glyphosate uptake in Roundup Ultramax and Engame was not sufficient in 30 min to control johnsongrass and that the herbicide on the surface was washed off. In addition, the weed control efficacy of the Engame plus Flame treatment was greater than that of the Roundup Ultramax on a

Table 2. The effects of the simulated rainfall on the activity of Engame, Engame plus Flame and Roundup Ultramax in johnsongrass, prickly sida and yellow nutsedge

Herbicide	Johnsongrass (% control)						Prickly sida (% control)							Yellow nutsedge (% control)						
	Duration of rain-free period (min) following herbicide application																			
	5	10	15	30	No rain	LSD 0.05	15	30	60	90	120	No rain	LSD 0.05	15	30	60	90	120	No rain	LSD 0.05
Engame	17	28	28	38	93	7	67	69	82	83	83	91	10	57	60	60	65	67	72	10
Engame + Flame	54	73	77	82	98	6	53	68	71	77	80	97	10	73	80	77	75	75	92	14
Roundup Ultramax	16	19	18	22	66	13	17	38	56	64	68	93	7	52	52	52	50	50	57	8

Herbicide rates: 890 g ae ha^{-1} for prickly sida and yellow nutsedge, 560 g ae ha^{-1} for johnsongrass. LSD, least significant difference.

glyphosate acid-equivalent basis. It might result from increased uptake and translocation of glyphosate.

Prickly sida control was nearly equivalent among the glyphosate formulations without rainfall and was >91% (Table 2). These results indicate that these products had similar control efficacy on prickly sida. However, in Roundup Ultramax, the control efficacy decreased from 93% without rainfall to 17, 38, 56, 64 and 68% at 15, 30, 60, 90 and 120 min rainfall delay after treatment, respectively. Rainfall had much less effect on Engame and Engame plus Flame control of prickly sida for the same rainfall delay (Table 2). The control of prickly sida was 67–83% at 15 and 120 min rainfall delay for Engame and 53–80% for Engame plus Flame. The control of prickly sida for each rainfall delay period was greater for Engame compared to Engame plus Flame. Flame might have facilitated the removal of glyphosate during rainfall in prickly sida.

The results presented here demonstrate that glyphosate performance was affected by the formulation, surfactant and simulated rainfall, and the effects were species-specific. Reddy *et al.* (1995) reported that bentazon had a similar activity on smooth pigweed and velvetleaf regardless of the adjuvant, but an organosilicone surfactant improved bentazon performance on hemp sesbania and sicklepod compared to a crop oil concentrate. In addition, Sun *et al.* (1996) reported that organosilicone surfactants greatly increased the rainfastness of primisulfuron in velvetleaf at 15 min after treatment. There might also be a strong surfactant and herbicide interaction on certain species, such that glyphosate uptake is greatly facilitated by components of the Flame surfactant.

Flame contains a tallowamine surfactant designed to enhance glyphosate mixtures (Loveland Industries 2004). Engame prepared for application has a pH of 2 (Platte Chemical Company 2001), which is related to the AMADS as a formulation component. This pH is well below the pK_1 of glyphosate, indicating that glyphosate is predominately in the protonated form (Franz *et al.* 1997). The efficacy of Engame was improved by Flame, and the other surfactants to a lesser extent, in johnsongrass and yellow nutsedge, which indicates that these surfactants can facilitate the uptake of the protonated form of glyphosate. These results also might indicate that the uptake of the protonated form of glyphosate is better than the salt forms of glyphosate present in Roundup.

Overall, our results support the findings of Feng *et al.* (2000), who showed that rainfastness was correlated to the speed and amount of glyphosate uptake. Indeed, Westra *et al*. (2003) reported that radiolabeled glyphosate uptake was three times faster with the Engame formulation compared to a standard formulation. A more rapid uptake would probably result in the rapid accumulation of a lethal dose of glyphosate in a given period. Molin *et al*. (2003) reported that Engame causes rapid subcellular and subcuticular damage to cotton leaves, which might be caused by the rapid uptake or entry of glyphosate into the leaves.

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